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Strategic Plan for Forest and Range Soils Research and Extension in British Columbia

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Strategic Plan for Forest and Range Soils Research and Extension in British Columbia

M. Curran, S. Berch, C. Bulmer, G. Hope, M. Kranabetter, P. Sanborn, R. Brockley, and D. Spittlehouse

BRITISH COLUMBIA

Ministry of Forests Research Program

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This document is intended for managers of government programs influencing the soil resource, policy specialists, scientists, departments, and individuals working or contemplating working on forest soils in British Columbia, clients in the forest industry and non-governmental organizations, and interested public. The document serves to help coordinate and guide new research efforts and the draft was widely circulated before the recent B.C. Science Council call for proposals. The document was compiled from several authors, acknowledged below, and effort has been made to make it read uniformly. Specific comments or questions should be directed to the primary author of the section in question. In some topic areas, more detailed lists of questions may be found in the 1996 B.C. Forest Soils Research Strategy available from the senior author or Research Branch. No formal list of publications has been provided for the various topic areas; these will be compiled in the future. For now many of these publications should be listed on the Ministry Research Branch and regional forest science websites accessible through: http://www.for.gov.bc.ca/research/, and the websites for other agencies involved in doing or funding forest soils research and extension in British Columbia (e.g., the Canadian Forest Service, universities, Forest Engineering Institute of Canada, B.C. Science Council, Forest Renewal BC).

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Part of this strategic plan is based on the original 1996 B.C. Soils Research Strategy developed by Marty Osberg, Bill Chapman, and others, based on a meeting of 32 soil scientists in Richmond, B.C. The initial draft of this new strategy was developed in early summer, 2000 and was compiled and edited by Mike Curran and Shannon Berch based on section input from Mike Curran (1.0, 2.1, 2.4), Chuck Bulmer (2.2), Paul Sanborn and Rob Brockley (2.3), Graeme Hope (3.1), Shannon Berch (3.2), and Marty Kranabetter (3.3). The draft version was widely circulated to practising soil scientists and other interested parties and clients. External reviews and specific comments were provided during the tight time frame by Doug Maynard, Canadian Forest Service (CFS); Margaret Schmidt, Simon Fraser University; Dave Basaraba, Crestbrook Forest Industries (now Tembec); Jacob Boateng, Ministry of Forests Forest Practices Branch; Mike Geisler, Ministry of Forests Nelson Forest Region, and Cindy Prescott and Kirsty Venner, University of British Columbia (UBC) Forest Sciences Department. Reviews were incorporated by Mike Curran with a brief review of the Executive Summary by Chuck Bulmer. The final draft was once again widely circulated to help provide guidance and co-ordination for new proposals being developed under the pending B.C. Science Council call for proposals. Afterwards, further reviews of the final version were provided by Mike Geisler, Nelson Forest Region, and Tom Terry and Ron Henninger of Weyerhaeuser. David Spittlehouse, Ministry of Forests Research Branch, provided the information relevant to the Framework Convention on Climate Change and the Kyoto Protocol (part of Section 1 and Appendix 1).

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This strategic plan describes goals, objectives, strategies, and knowledge gaps for the forest soil research and extension program in British Columbia. The program addresses government (public) and forest industry priorities related to soil conservation and sustainable forest development. It is consistent with the strategies and plans of the B.C. Ministry of Forests Research Program at provincial and regional levels and other agencies' plans and programs such as Forest Renewal BC's Strategic Plan.

Coordinated implementation of the soil research and extension program will promote synergy and reduce potential for duplication of effort, resulting in financial savings and more timely and applicable results. This will be facilitated through the formation of a technical subcommittee on British Columbia forest soils that will include members of government agencies, universities, industry, consultants, non-governmental organizations, extension partnerships and interested public.

A key theme of this strategy is the recognition that the longer-term knowledge gaps include the need to demonstrate good land stewardship and sustainable forest management within the environment of increased scrutiny of government policy, legislation, and permit approvals related to forestry. To this end, the maintenance and establishment of long-term research and operational trials are vital to achieving the goals presented herein.

Goals

The primary goals of British Columbia's integrated forest soil research and extension program are:

1. To improve knowledge of soil and its role in forest ecosystem function and productivity, and
2. To provide tools for the use of this knowledge in forest resource management.

Research and extension efforts will focus on achieving the goals by addressing two key objectives shown in the table below. Three other extension-related objectives are included in the main text; these will be achieved during extension of the results from Objectives A and B. Extension will be facilitated through current job functions of government soil scientists, interagency collaboration, increased focus on timely publication of results, and collaboration with extension partnerships.

Objective A: Provide soil science support to help government achieve its mission to manage and conserve the province's forest and range resources in a manner that balances economic, ecological, and social benefits for all British Columbians.

Objective B: Provide soil science support to the vision that British Columbia will be universally recognized as a leader in sustainable management of forests and grasslands.

Strategies

In order to meet these goals and objectives, a number of strategies are identified in this plan. The strategies relate to funding, maintaining key, long-term research installations, timely extension, and prioritization of work.

Operational, National, and International Frames of Reference

This strategic plan identifies key knowledge gaps that require attention from the various scientists and specialists contributing to forest soil management in a) the operational context for British Columbia, and b) the national and international forums. It is proposed that British Columbia needs to contribute more to the advancement of international soil science, and that British Columbia has much to contribute to, and benefit from, the development of international protocols and reporting frameworks.

Common Themes among Knowledge Gaps

For all knowledge gaps, "five basic needs" or priorities, are:

1. Produce formal publications on previous measurements/trials.
2. Monitor (re-measure tree growth and soil conditions) and maintain existing research and operational trial installations.
3. Expand existing research and operational trial installations to cover geographic areas (ecosystems and soil types) not represented.
4. Initiate research and operational trials that address new practices and issues.
5. Apply existing knowledge in models and spatial analyses related to tree-growth prediction and management options.

Key Knowledge Gaps (discussed in detail in the attached Plan)

For Objectives A and B, the knowledge gaps and issues detailed in the text are:

Objective A:

Provide soil science support to help government achieve its mission to manage and conserve the province's forest and range resources in a manner that balances economic, ecological, and social benefits for all British Columbians.

Key knowledge gap	Issue
Soil disturbance management	Maintain and revise the management framework for predicting sensitivity of soil to disturbance, and provide strategies to minimize detrimental disturbance during various forest or range management operations.
Soil rehabilitation	Improve the knowledge base for using soil rehabilitation as a strategy to maintain or increase timber supply and to facilitate ecosystem restoration on sites degraded by forest operations.
Enhancing soil productivity	Test if it is possible to increase the productive capability of forest soils in an ecologically sustainable fashion (e.g., through soil management or amendments).
Soil landscape variability	Quantify soil (site productivity) variability at the landscape and stand levels to help guide management and investment decisions, and maximize the utility of landscape-level soil information.

Objective B:

Provide soil science support to the vision that British Columbia will be universally recognized as a leader in sustainable management of forests and grasslands.

Key knowledge gap	Issue
Long-term soil productivity	Participate in the international long-term soil productivity network by maintaining and developing benchmark study sites to determine long-term effects of soil disturbance (organic matter loss and soil compaction), test and demonstrate sustainable forest management, and support guideline revisions.
Soil ecology (below-ground biodiversity)	Develop better understanding, active management strategies, and appropriate indicators of soil biodiversity, below-ground ecosystem function, processes, and components, including natural disturbance regimes.
Soil–vegetation interactions	Understand interactions between plants and soils to improve our ability to predict and document the effects of forest management decisions and support guideline revisions.

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This strategic plan describes goals, objectives, strategies, and knowledge gaps for the forest soil research and extension program for British Columbia. This strategy is one of several discipline-specific strategies developed at the provincial level.

Using an integrated approach, the program addresses government (public) and forest industry priorities related to soil conservation and sustainable forest development. The program is consistent with strategies and plans of the B.C. Ministry of Forests Research Program at provincial and regional levels, and similar plans of other related agencies, such as Forest Renewal BC. Coordinated implementation of the soil research and extension program will be facilitated through external program reviews, and possibly through the formation of a committee on B.C. forest and range soils. External program review might make use of the newly created "technical peer review committee" of the Northwest Forest Soils Council. A committee on B.C. forest and range soils could include representatives of government agencies, universities, industry, consultants, extension partnerships, non-government organizations, and interested public.

A key theme of this strategy is the recognition that the longer-term knowledge gaps include the need to demonstrate good land stewardship and sustainable forest management within the environment of increased scrutiny of government policy, legislation, and permit approvals related to forestry. To this end, the maintenance and establishment of long-term research installations are vital.

1.1 Goals and Objectives

Goals The primary goals of British Columbia's forest soil research and extension program are:

1. To improve knowledge of soil and its role in forest ecosystem function and productivity, and
2. To provide tools for the use of this knowledge in forest resource management.

Objectives Research and extension efforts will focus on achieving the goals by addressing the following objectives:

A. Provide soil science support to help government achieve its mission to manage and conserve the province's forest and range resources in a manner that balances economic, ecological, and social benefits for all British Columbians.
B. Provide soil science support to the vision that British Columbia will be universally recognized as a leader in sustainable management of forests and grasslands.
C. Work with resource managers and their operational staff to provide innovative solutions to the increasingly complex, high-impact, soil-management problems in British Columbia.
D. Across the agencies involved in the Technical Subcommittee, develop and maintain a balanced program of operation consultation, applied soil research, and extension that focusses on priorities consistent with the above goals.

E. Contribute to the advancement of soil science and to the global credibility of sustainable development in British Columbia by publishing research results and benchmark soil conservation efforts in internationally recognized scientific journals.

Objectives A and B form the essence of this strategic plan. Objectives C, D, and E will be achieved during extension of the results of Objectives A and B. Extension will be facilitated through current job functions of government soil scientists, interagency collaboration, increased focus on timely publication of results, and collaboration with extension partnerships. This plan recognizes that basic and applied, excellent science is fundamental to the forest sector being recognized as credible in sustainable resource management issues, as well as to the development of acts, regulations, and policies.

1.2 Strategies

In order to meet the above goals and objectives, a number of strategies must be pursued:

Secure funding There currently is not enough funding do to detailed work in all the knowledge gap areas identified in this strategic plan. It is up to the individual scientists, their managers, and others working on forest and range soils in British Columbia, to ensure available funds and resources are spent on the highest-priority information needs. Work on short-term knowledge gaps needs to be balanced with support for the longer-term, strategic information needs. Strategies to maximize efficiencies with available funding include increased inter- and intra-agency collaboration, working on integrated research sites with other disciplines, and maximizing involvement of graduate students. These strategies could be facilitated and promoted through the establishment of a committee on B.C. forest and range soils (described below) that will also help to lever available funds and ensure that the soil resource gets its share of attention.

Establish and maintain key long-term research installations ("gems") Long-term research installations represent large investments in integrated projects. They typically involve more than one discipline or agency, and form the scientific basis for future land management and policy decisions. These projects have sound, peer-reviewed experimental design, and may be unique or networked installations that represent regionally important conditions. As these "gems" will be important into the future, scientists and their managers need to:

- Safeguard, maintain, and regularly report on these studies.
- Address funding risks over time and develop contingency plans for maintenance and monitoring, such as district/licensee cooperation/help.
- Clearly identify key installations by developing and maintaining a directory of test sites, a database, and map notations

Produce operationally relevant, timely products, and provide efficient consulting support to government, industry, and non-governmental organizations Work collaboratively with operational staff and management to develop decision guides and other tools for common resource management issues. Ensure that results from consultations that address

common problems are distributed to other clients. Ensure timely publication of operationally relevant products, not just from government scientists, but also through collaboration with other agencies and extension partnerships.

To facilitate coordination and extension, consider establishing a committee on British Columbia forest and range soils Coordinated implementation of the soils research and extension program could be facilitated through the formation of a committee on B. C. forest and range soils issues. The subcommittee will include members of government agencies, universities, industry, consultants, extension partnerships, non-governmental organizations, and interested public.

Prioritize work based on severity and extent Use this concept to ensure that the focus is on the highest-priority, highest-payback items. Severity can be considered in terms of potential effects on resources (e.g., timber productivity gain or loss). Extent can be considered in terms of the extent of geographic area to which the problem applies, or number of permit areas or individual resource managers affected by the issue. The most severe, most extensive problems normally deserve the highest priority.

1.3 Operational, National, and International Frames of Reference

Almost two-thirds of British Columbia, 59 million ha, is forest land. A quarter of the province supports forests that are considered available and suitable for timber harvesting, and less than 1% of that quarter is typically harvested in any given year. Ninety-four percent of the forest land is publicly owned, and the B.C. Ministry of Forests has the mandate to manage the timber, range, and recreation resources of this land while taking into consideration all other resource values.

In addition to other professionals, the Ministry of Forests employs soil scientists in the dual roles of providing consultation and extension on operations and policy development, as well as undertaking focussed research on high-priority knowledge gaps. The Canadian Forest Service(CFS), local universities, and some forest companies also employ scientists who are focussed on soil management and conservation issues. Some Ministry of Forests forest districts employ earth scientists who provide consultation and extension on soil-related issues as well as watershed-management issues. The Ministry of Forests structure is somewhat similar to the U.S. Department of Agriculture Forest Service, except that the Ministry of Forests has few separate research stations and scientists whose sole function is research; also, British Columbia's forest districts do not have their own soil scientists. In both jurisdictions, other agencies and numerous consulting scientists also provide additional operational and research services, as demand and funding warrant.

This Strategic Plan for Forest and Range Soils Research and Extension in British Columbia identifies key knowledge gaps relevant to forest soil resource management in the operational context for British Columbia, and in national and international forums.

Operational context Scientists and policy specialists within forest resource management organizations are required to develop and refine forest management tools, and provide recommendations on operations and policy to guide stewardship of the forest land-base. Table 1 contains the

components of this adaptive management process, including short lists of some of the key products or developments under way. This on-going, adaptive management is similar to that referred to as a "reliable process" by the Weyerhaeuser Technology Centre.

TABLE 1 *Example of how soils science information fits into the operational context of forest resource management in British Columbia*

Component	Examples of products and on-going soils work
Strategic direction	Soil sensitivity and measurement systems. Biogeoclimatic ecosystem classification framework.
Guidelines	*Forest Practices Code of British Columbia Act*, regulations, guidebooks. Regional and district directives.
Training	Standard provincial training workshops. Regional and custom workshops and field days. Operationally oriented conferences and workshops. One-on-one consultations and mutual learning. Tools for common information needs (e.g., field handbooks, field cards, videos). Limited computer models to simulate options. Tours of major research installations and trials.
Best management practices	Published field handbooks and field forms. Extension Notes, Working Papers, and other publications. Evolution of guidelines and practices based on research results and practical innovation.
Monitoring	Monitoring criteria and methods. Reporting for Montreal Process.
Databases	Soil disturbance. Baseline soil condition and productivity?
Research and development	Internal Ministry of Forests research strategies/programs. Other agencies' strategies and programs. Individual scientists' programs. Inter-agency and international collaboration. Published, peer-reviewed, scientific papers. Long-term research and demonstration sites.

Research and development is an integral part of adaptive management. Scientists are involved in research and operational trials aimed at filling the key knowledge gaps. The new information provided by research and operational trials supports the testing, refinement, and evolution of forest management guidelines and practices.

This Strategic Plan identifies the key knowledge gaps for forest soil management in British Columbia. It is up to the scientists in the various organizations, and to their managers and clients involved in resource management issues, to develop individual, focussed programs aimed at filling these and other emerging knowledge gaps. At the same time, the soil

scientists will continue to provide technical soil-science support to operations, policy development, and the national and international forum.

National and international contexts The Ministry of Forests has what may be considered some of the most comprehensive and potentially restrictive regulations governing soil conservation, as covered by the *Forest Practices Code of British Columbia Act* and accompanying regulations and guidebooks. In the case of the soil-conservation components, considerable scientific information and professional opinion formed the foundation for regulations and guidebooks; these continue to evolve as new information and innovation are recognized under the legislative framework.

Soil-disturbance guidelines first started as steep-slope guidelines in the 1970s and evolved into ground-skidding and then overall harvesting-disturbance guidelines in the 1980s. In the late 1980s and early 1990s, considerable research and trial work was done on various aspects of the soil-disturbance hazard rating, and on the soil-disturbance monitoring and measurements components of the system. Several tools and training packages were developed and these formed the basis of the soil-conservation components of the Forest Practices Code.

Unfortunately, similar to other aspects of forest management in British Columbia, few of the soil studies, classification systems, and monitoring criteria were formally published in the international forum. It is possible that international opinion about forest practices in British Columbia, and British Columbia's share of the international marketplace, has been negatively affected by this lack of consistent, demonstrated, scientific contribution to the international knowledge base on forest practices. Scientists and their managers have collectively invested in producing a considerable wealth of scientific information that needs to be published in international journals.

Two national and international areas of specific relevance to the soil-science program in British Columbia are soil-disturbance monitoring and reporting under the Montreal Process, and soil carbon pool determination and monitoring under the Kyoto Protocol and the Framework Convention on Climate Change (FCCC). These are briefly described below.

Soil-disturbance reporting for comparing research results and assessing progress, relative to the Montreal Process on criteria and indicators
In order to communicate research results, compare forest practices and guidelines relative to international protocols, and provide necessary provincial-level reporting on these protocols, there is a need for a common protocol for describing soil disturbance and soil susceptibility to specific disturbance processes (e.g., compaction). This need has been demonstrated in discussions on collaborative studies in the Pacific Northwest over the last few years, and more recently at the Long-Term Soil Productivity 2000 (LTSP2000) meeting and associated U.S. Forest Service (USFS) Regional Soil Scientists' meeting in Louisiana.

The intent is not to replace existing criteria in various jurisdictions, but rather to create a common "language" for communicating and describing the type of soil disturbance being studied. Combined with a risk rating system, a common "language" enables intelligent discussion and comparison of the relative importance of given disturbance types to tree growth and site processes (based on site-specific conditions). For example, as demonstrated at the LTSP2000 workshop, the kind of rutting that would be of concern on a shallow, mountain soil in British Columbia might not be considered a

concern on deeper, wetter, alluvial soils in piedmont areas in the southeastern United States.

Everyone involved must be careful not to imply value judgements based on disturbance types, measurement protocols, or proposed risk/hazard comparison ratings. While "a rut is a rut" can hold true for defined disturbance types, the outcome for tree growth can range from beneficial to detrimental, based on many factors, including soil development (age), texture, drainage, climate, tree species, etc.

Based on discussions and a recent draft discussion paper by the senior author, this "common protocol" would need to include these elements:

1. Internationally agreed-upon and simple soil-disturbance categories and measurement techniques that enable global comparison and transportability of research results.
2. Some way of expressing soil types in terms of compaction, displacement, and, perhaps, erosion risk.
3. Agreement on what a reliable process for monitoring soil disturbance and for regulating operations should contain.
4. Approaches to using the results of operational monitoring to satisfy reporting requirements under the Montreal Process.
5. A comparison of soil-disturbance guidelines across various soil and climatic conditions.

Having a common protocol that includes these elements will help pave the way for a more seamless process of national and international reporting by facilitating collection of data from states, provinces, USFS regions, etc. on a common platform. This also further adds to the transportability and international relevance of research results.

National agencies with an existing mandate to set up or facilitate reporting under the Montreal Process should probably take the lead in this area (e.g., CFS and/or USFS). Agencies with existing monitoring and reporting systems and databases (e.g., Weyerhaeuser, Ministry of Forests) should contribute to the process. Soil scientists and policy staff in the Ministry of Forests would be able to contribute to this initiative, and they may help lead the process and review in some areas.

Soil carbon pool determination and monitoring under the Framework Convention on Climate Change and the Kyoto Protocol Serious knowledge gaps in understanding carbon pools in soil affect the ability of British Columbia and Canada to report on progress relative to these agreements.

Globally, soils contain about 3.2 trillion tons of carbon within the top 1.8 m. An estimated 2.5 trillion tons are in the form of organic carbon and the remaining 0.7 trillion tons are inorganic carbon. The carbon pool in soil is 4.2 times the entire atmospheric pool, and 5.7 times the biotic pool. A relatively small increase (or decrease) in soil carbon—taken from (or added to) the air—could significantly affect the amount of carbon in the atmosphere. Therefore, measuring the amount of carbon stored in soils is crucial to understanding carbon cycling in terrestrial ecosystems.

The Framework Convention on Climate Change, adopted in 1992, states that "Each Party shall... limit its anthropogenic emissions of greenhouse gases and protect and enhance its greenhouse gas sinks and reservoirs." These activities are meant to further the objective of achieving stabilization of greenhouse gas concentrations in the atmosphere at a level that would

prevent dangerous anthropogenic interference with the climate system. Pursuant to the Kyoto Protocol, Canada undertook to reduce its greenhouse gas emissions by 6% below the 1990 levels by 2008–2012. Analysis by National Resources Canada suggests that Canada's annual greenhouse gas emissions, under a business-as-usual scenario, will have to be reduced by more than 20%.

Article 3 of the Kyoto Protocol emphasizes that national reports on sources, sinks, and reservoirs of greenhouse gases resulting from human-induced, land-use change and forestry activities must be made, and these reports must be transparent and verifiable.

Environment Canada[1] provided a detailed analysis of the current state of knowledge and future needs in addressing the requirements of the Kyoto Protocol as well as those of probable future agreements on land use, land-use change, and forestry. With respect to forest and range soils, the relevant knowledge gaps are listed in Appendix 1 of this plan, and summarized below:

- National inventories and understanding of carbon stocks in forests ecosystems.
- Understanding how soils affect carbon dioxide levels in the atmosphere.
- Understanding how the carbon stock in the total carbon system changes, particularly in below-ground, dead organic, and dissolved organic carbon pools within ground and surface water.
- Improved techniques for confidently scaling up data on changes in carbon stock in highly variable ecosystems, from the process level to ecosystem, landscape, and national scales.

Priorities for action and recommended studies have been drafted to address these issues. Items relevant to this strategy appear in Appendix 1 and include items such as decomposition of soil organic matter and coarse woody debris, and response of the soil carbon dynamics to soil disturbance.

The material above provides the operational, national, and international contexts for research and extension of forest-soil science in British Columbia.

Following is a description of how the knowledge gaps were identified, with a discussion of the themes common to all topic areas.

1.4 Development of this Plan

The 1996 Forest Soils Research Strategy was developed by soliciting input from representatives of the forest industry, First Nations, and scientists working in colleges, universities, independent research organizations, and federal and provincial government research agencies. Input to the strategy was obtained from all regions of the province through the active participation of 32 scientists and industry representatives in a 1-day workshop designed to identify the priority topic areas for research, and the key knowledge gaps in each topic area that require research proposal development. The 1996 strategy was organized according to the strategic objectives of Forest Renewal BC and contained specific questions under each topic areas.

This new strategy is based on the authors' understanding of the issues and an update and reorganization of the issues identified in the 1996 B.C. Forest Soils Research Strategy.

1 Environment Canada. 1999. Sinks Table Options Paper: Land-Use, Land-Use Change and Forestry in Canada and the Kyoto Protocol, 23 Sept. 1999. Ottawa, Ont.

This new strategy was reviewed by knowledgeable individuals from the CFS, Simon Fraser University, forest industry, and Ministry of Forests operational staff. This new strategy is intended as an update and expansion to put the science into operational, national, and international contexts, and to identify key knowledge gaps. The knowledge gaps identified in this strategy are organized by topic areas that are independent of funding source. The objective is to provide an overview of what we, as scientists responsible for the conservation of the soil resource, consider to be the real information needs.

Common themes among the knowledge gaps For all knowledge gaps, emphasis will be placed on publishing the results of previous trials. While interim reports contribute to the evolution of government policy and operational practices, there is also a specific need to publish peer-reviewed scientific papers as well as publications aimed at the resource manager level. Scientific publications contribute to the advancement of science, and demonstrate to the global marketplace that British Columbia is serious about sustainable development. In many cases, additional funding will be needed to fully realize the benefits of publishing existing soil research results.

A network of key research installations has already been created through funding from the Ministry of Forests, the Federal-Provincial Forest Resource Development Agreement (FRDA), Forest Renewal BC (FRBC), and other past and existing funding initiatives. These installations need periodic re-measurement of tree growth and soil conditions. In many cases, more funding will be needed to continue maintaining these important sources of long-term data because many of these installations were created under special funding opportunities. Therefore, for all knowledge gaps, the "five basic needs," representing a listing of priorities, are:

1. Produce formal publications on previous measurements/trials.
2. Monitor (re-measure tree growth and soil conditions) and maintain existing research and operational trial installations.
3. Expand existing research and operational trial installations to cover geographic areas (ecosystems and soil types) not represented.
4. Initiate research and operational trials that address new practices and issues.
5. Apply existing knowledge in models and spatial analyses related to tree-growth prediction and management options.

Background rationale The soil on a forest or range site is one key factor in determining site productivity for forest growth and ecosystem function. Without careful management, soil may well be considered a "non-renewable resource." However, with knowledgeable management, soil productivity and its contribution to ecosystem health can probably be sustained, or perhaps even increased.

Research elsewhere suggests that there may be potential for enhancing timber or other measures of ecosystem productivity by implementing intensive soil-management measures. However, enhancing site productivity is contingent upon developing a sound understanding of both:

- the effects of forest practices on fundamental forest soil properties, such as physical characteristics, organic matter and nutrient content, and soil biological diversity; and

- the relationships between these fundamental soil properties and long-term soil productivity.

Within the operational, national, and international frameworks provided in this strategic plan, studies of forest soil should be solicited, designed, and conducted to enhance the level of understanding of these complex forest soil processes and relationships. This is consistent with the goals of individual funding agencies such as FRBC. Coordination of these research efforts would be facilitated through the development of a technical subcommittee on British Columbia forest soils.

This strategic plan has been produced to ensure that forest soil research projects are developed to address key information gaps. Large investments have already been made in existing research and operational trial installations that address a number of key topics. If funds and resources are limited, continuation and re-measurement of existing projects should be considered prior to embarking on new projects.

The Strategic Plan for Forest and Range Soils Research and Extension in British Columbia provides general guidance on research and extension needs. It is the responsibility of any funding agency to use this information in a technical committee process that prioritizes funding opportunities relative to agency priorities. However, all agencies should recognize that, in the absence of research results on basic ecosystem functions and their response to basic treatments, any intensive management or value-added research is of dubious value.

Roles of basic and applied research, operational trials, and retrospective studies Manipulative experiments have obvious advantages over retrospective studies with respect to providing detailed knowledge of the initial site conditions, exercising control over replication, and ensuring that treatments are uniformly imposed on replicate sites. However, replicated experiments can be quite costly and often the core treatments can be applied in an operational setting for less cost. These "operational trials" can still yield scientifically valid information, particularly when they are well designed and networked with the formal experimental sites. Within many of the knowledge gap areas, the potential for conducting retrospective studies or operational trials should be carefully considered. Retrospective studies can also be costly, and, depending on the information gap and forest practice of interest, may be limited in their ability to provide definitive information or establish "benchmark sites" for testing sustainable forest management. A mix of well-designed retrospective studies, operational trials, and *basic and applied research* installations will likely yield the most useful information in the short and long terms.

Role of computer modeling Results from all studies can be very useful in supporting the development of computer models of physical processes. Computer models have a role to play in investigating the potential effects of forest practices while scientists and resource practitioners gather the results of long-term studies. Computer models are also important in identifying knowledge gaps that may be tested through further research. Although not specifically discussed in detail, modelling is a natural extension of all of the research topics that follow.

1.5 Organization of the Knowledge Gaps

Knowledge gaps identified in this strategic plan are organized into two main groupings, Section 2 and Section 3, based on the first two objectives of this strategic plan. In each section, there are three to four topic areas believed to cover the main issues, relevant existing work, and future information needs. For each topic area there is a two- to four-page write-up that covers:

- Issue (e.g., soil compaction and organic matter depletion benchmark studies related to long-term site productivity).
- Existing research—a general description of key, on-going work (e.g., biogeoclimatic zones or soil types covered).
- Satellite research trials (e.g., smaller, one-off trials in existence?).
- Research gaps—a general list of needs in addition to the "five basic needs" list in the Introduction above. These may or may not be ranked (e.g., biogeoclimatic zones or soil types not covered).
- Opportunities for operational trials, adaptive management (e.g., further satellite "trials," ideas for trials initiated or funded by Resource Management Plans).
- Links to policy and guidelines, such as the Forest Practices Code, Higher-Level Plans, Timber Supply Reviews, FRBC strategic direction/goals, etc.
- General discussion of the Canadian Council of Forest Ministers Six Criteria for Sustainability.
- Discussion of general extension needs for each topic.

Soil climate is an essential part of all of the long-term and tree-growth or ecological studies, although soil climate is not listed as a separate topic. (This item is partially covered in the "Forest Climate Research Strategy B.C. " by Dave Spittlehouse.)

Provide soil science support to help government achieve its mission to manage and conserve the province's forest and range resources in a manner that balances economic, ecological, and social benefits for all British Columbians.

It is recognized that the forest ecosystem cannot be managed without some form of access. It is also recognized that, in terms of timber production, some types of disturbance actually appear to be beneficial or neutral in terms of long-term ecosystem productivity. However, there is also concern about the potential for degradation of the soil because of compaction, displacement, erosion, and other processes that are not fully understood. Forest managers must be able to demonstrate in a convincing way that forest practices are not causing environmental degradation or a decline in forest productivity or ecosystem health. In order to do this, techniques for assessing soil sensitivity and soil disturbance need to be developed and maintained (Section 2.1). In addition, techniques for restoring the soil (Section 2.2), and opportunities for enhancing soil/site productivity (Section 2.3), need to be explored. The potential for restoration or enhancement needs to be put into the context of risk management in terms of the potential costs, benefits, and tradeoffs that typically form the basis of resource management decisions. All work related to soil needs some understanding of the background variability (Section 2.4), either at the landscape or stand level. It also needs to be founded on, and pursued concurrently with, a basic understanding of the implications of various soil disturbances for tree growth and other measures of ecosystem health (Section 3).

2.1 Disturbance Management

Issue Maintain and revise the management framework for predicting sensitivity of soil to disturbance, and provide strategies to minimize detrimental disturbance during various forest or range management operations.

Existing research

Soil-sensitivity rating system The Forest Practices Code requires that soil-disturbance hazard be assessed whenever ground-based operations are planned. Minimal direct research has been undertaken on these hazards, but some previous CFS studies and the new Long-Term Soil Productivity studies have addressed aspects of the Soil Erosion, Soil Displacement, and Soil Compaction Hazards.

Ongoing research on soil erosion due to roads and on landslide attributes are helping to develop and calibrate sensitivity rating systems in these fields.

Minimizing detrimental disturbance This area has received considerable efforts that can be categorized as follows:

a) Soil-disturbance measurement
   Considerable work was done in the late 1980s and early 1990s in cooperation with the CFS. Current soil disturbance measurement criteria are based on visually recognizable characteristics of various disturbance types considered to be of concern ("potentially degrading") for site

productivity or site hydrology and erosion. However, apart from measurement guidebooks, no formal publications exist.

b) Harvesting disturbance
Considerable work was done in the 1980s and early 1990s in cooperation with the CFS and the Forest Engineering Research Institute of Canada (FERIC). Oldest installations are in the southern interior and are just now yielding results in terms of mid-term tree-growth effects. Few formal publications exist, and much ongoing work is in the process of being reported. Some sites are overdue for re-measurements, partly due to lack of funding.

c) Mechanical site preparation
Considerable work was done under FRDA programs in the northern and southern interior, with less work since then. A few valuable installations exist; some are overdue for re-measurements, often due to lack of funding.

d) Prescribed burning
Considerable work was done under FRDA programs, particularly on the coast and southern interior, with less work since then. A few valuable installations exist, with some overdue for re-measurements, often due to lack of funding.

e) Root-removal treatments
Some sites have been studied for as long as 30 years, with true, replicated trials just past 15-year measurement; most are in the southern interior and on the coast. Considerable work has been done under FRDA II and FRBC programs, with several valuable installations needing periodic re-measurements in the future.

f) Alternative root-rot treatments
There has been recent interest in *Hypholoma fasiculare* as a naturally occurring "biological control" agent for *Armillaria* root-disease control, which may negate the need to remove stumps from the soil. Limited trials have been installed in selected locations in the southern interior. Further funding is required in this area, and apparently the CFS is pursuing some other "biocontrol" agents for *Armillaria*.

g) Range-management practices
Ranging cattle on forest land has been proven to cause soil puddling and compaction in concentrated areas. Some recent investigations over more dispersed areas are being summarized, but are limited in geographic scope.

Research gaps In addition to the "five basic needs" mentioned in the Introduction, new, unique needs are listed under each subcategory, below. An asterisk (*) indicates areas where operational trials may be feasible.

Soil-sensitivity rating system Fine tuning of soil-disturbance hazard keys for the range of soil types (e.g., low versus higher clay content soils) is needed.

Minimizing detrimental disturbance

a) Soil-disturbance measurement
- Further investigations demonstrating reproducibility of visual soil-disturbance-type assessment and measurement results by field staff.*
- Fine tuning of soil-disturbance criteria ("counted disturbance") for the range of soil types (e.g., low versus higher clay content soils).

b) Harvesting disturbance
- Further retrospective work to confirm/adjust Timber Supply Review "netdowns" for harvesting-related soil disturbances.*
- Further work on soil disturbance related to partial cutting, and potential long-term effects.
- Further work on the effects of non-bladed (main) trails on tree growth and site hydrology.
- Further work on soil trafficability and seasonal soil constraints.
- Further work on light compaction in relation to economically viable harvesting strategies.*
- Correlation of soil-disturbance guidelines across bordering jurisdictions, including Alberta, Yukon, and the United States.

c) Mechanical site preparation
- Covered by the "five basic needs."

d) Prescribed burning
- Investigation of the effects of ecosystem maintenance and restoration burning on soil productivity.*
- Investigation of the assessment and management of erosion hazards after wildfire.*

e) Root-removal treatments
- Further refinement of technique and equipment to limit level of soil disturbance.*

f) Alternative root-rot treatments
- More *Hypholoma* and other "biocontrol" trials, and continued monitoring of existing trials.
- Perhaps some refinement of stump inoculation technique.

g) Range-management practices
- Further study on impacts of dispersed grazing, including seasonal (wet) soil conditions.

Operational trials, adaptive management, and similar opportunities In all areas, considerable opportunity exists for undertaking operational trials that build on the factors studied in the larger research installations. A number of research installations have also been started based on the adaptive management approach. The areas marked with an asterisk above (*) have definite potential for operational trials, either alone, or associated with formal research trials. A number of these might fit well under the Resource Management Planning process of Forest Renewal BC.

Links to policy, guidelines, plans, Timber Supply Reviews, and strategic direction

- The soil conservation components of the Forest Practices Code are largely supported by research in all areas covered by this strategy, but most directly by research in this area.
- Timber Supply Review "netdown" factors for soil disturbance will continue to be refined by research and operational trials in this area.
- Forest Renewal BC's key Strategic Objectives are supported by research in this area, for example:

  Sustainable Harvest—research in this area will contribute to guiding investments in site preparation based on longer-term research results and testing of the assumption that site preparation will enhance forestry.

  Strengthen Sustainable Forest Management (Enhance Knowledge)—as noted above, this research area addresses some key indicators of sustainable forest management.

Indicators of sustainability Research in this area addresses several indicators listed by the Canadian Council of Forest Ministers, including:

Criterion 2.0 Maintenance and enhancement of forest ecosystem condition and productivity, and
Criterion 3.0 Conservation of soil and water resources.

Comments on extension needs Soil disturbance associated with machinery operations has always represented a high demand for extension and consultation. This demand is expected to continue or increase into the future.

2.2 Soil Rehabilitation

Issue Improve the knowledge base for using soil rehabilitation to maintain or increase timber supply and to facilitate ecosystem restoration on sites degraded by forest operations.

Existing research Much of the knowledge gained over the past 20 years is documented in publications, reports, and extension materials produced by the projects listed below.

Completed research Numerous projects have been recently completed, though in some cases the sites are still available for longer-term monitoring. These include a problem analysis of forest soil rehabilitation in British Columbia, early studies of soil rehabilitation in the Prince George Forest Region, and various retrospective studies of soil rehabilitation in the British Columbia interior.

On-going research A number of active research projects are continuing to provide important information. Continued monitoring of tree growth and soil conditions is a priority. Below are examples of the type of on-going projects:

- Soil rehabilitation research and demonstration: Aleza Lake Research Forest.
- Rehabilitation of forest roads and landings with wood waste.

- Tree growth on rehabilitated skid trails in the Nelson Forest Region.
- Use of biological inoculants and special stock types for soil rehabilitation.
- Soil rehabilitation research at LTSP.
- Operational trials of soil rehabilitation in the Cariboo.

Research gaps The existing/on-going trials are addressing many of the specific information needs identified in the soil-rehabilitation problem analysis undertaken in 1998. New efforts should build on the previous results, and also address the following gaps:

- The network of research sites needs to be expanded to cover geographic areas (ecosystems) not represented. Particularly, more research sites are needed in the northeast and on the coast.
- More information is needed on the benefits and costs associated with topsoil salvage/recovery, on low-cost techniques for topsoil salvage, and on the use of alternative materials including waste products.
- More information is needed on the factors (physical, chemical, and biological) affecting tree growth on degraded and rehabilitated soils. Such information will assist the development of low-cost rehabilitation techniques that are effective.
- Dispersed rutting is often difficult to rehabilitate and can cause deranged drainage in wetter areas. Research on the effects of this disturbance on productivity and ecosystem function, and on techniques for amelioration, is warranted.
- The role of soil physical properties in compaction and de-compactibility of British Columbia soils needs to be investigated.
- Efforts to apply existing knowledge to harvesting systems utilizing temporary access need to be supported.

Operational trials, adaptive management, and similar opportunities Considerable opportunity exists to address some of the information needs through operational trials. To help increase the benefits of trials, Ministry of Forests scientists are available to provide protocols (some exist), or to be directly involved in establishing, monitoring, and reporting on operational trials.

Links to policy, guidelines, plans, Timber Supply Reviews, and strategic direction

- Timber Supply Review "netdown" factors for soil disturbance will continue to be refined by research and operational trials in this area.
- Forest Renewal BC's key Strategic Objectives are supported by research in this area, for example:

  Sustainable Harvest—research in this area will contribute to guiding investments in soil rehabilitation based on longer-term research results, and testing of the assumption that rehabilitated areas will contribute to timber supply.

  Enhancing Environmental Values—research in this area is directly applicable to efforts to restore damaged ecosystems and watersheds.

Indicators of sustainability Research in this area addresses several indicators listed by the Canadian Council of Forest Ministers, including:

Criterion 2.0 Maintenance and enhancement of forest ecosystem condition and productivity, and
Criterion 3.0 Conservation of soil and water resources.

Comments on extension needs There is a high demand for extension and consultation on soil rehabilitation. This demand is expected to continue or increase into the future.

2.3 Enhancing Soil Productivity

As competing social demands place greater pressures on the operable forest land base, pressure is also mounting to increase the productive capability of the remaining forest land. Developing forest management techniques capable of increasing the productivity of forest soils in a sustainable manner requires a thorough understanding of soil properties and processes and how they are modified by specific forest practices under a wide range of ecological conditions. Various manipulations, ranging from simple site preparation to full-blown, incremental soil additions or fertilization have been shown to increase longer-term productivity in other parts of the world.

Nutrient deficiencies, notably for nitrogen, exist in many forest types in British Columbia. Fertilization has produced worthwhile gains in wood production for some species on some sites, but for much of the province, there is insufficient knowledge of response behaviour to support sound decisions on investments in forest fertilization. Good decisions also require a better understanding of the fate of applied nutrients and the effects of nutrient-management practices on ecosystem processes, both terrestrial and aquatic.

More recently, results from longer-term site-preparation trials are demonstrating beneficial effects extending beyond 15 years. There is a need to evaluate if certain forms of site preparation, or more aggressive tillage or subsoiling, may have long-term benefits or detrimental effects.

The need to manage human waste, wood waste, and co-generation waste (e.g., ash) presents opportunity for soil amendments and even irrigating with waste water, which may increase the fertility and productivity of forest sites.

Issue Test if it is possible to increase the productive capability of forest soils in an ecologically sustainable fashion (e.g., through soil management or amendments).

Existing research

Site preparation This area was discussed briefly in Section 2.1 Disturbance Management. Considerable work was done under FRDA and FRDA II. Some major installations are either being reported or are coming up for re-measurement. Some may consider root-removal trials, discussed in Section 2.1, to present an opportunity to enhance productivity. Lack of funding has limited re-measurements on several site-preparation trials.

Very little work has been done on tillage, but some work on highly disturbed soils suggests that damage to soil structure may be long-lived.

Soil amendments This area was discussed briefly in Section 2.2 Soil Rehabilitation. Some work has been done on spray-irrigation operations and

sludge-disposal investigations (e.g., Vernon and Cranbrook irrigation areas). Some work was started under FRBC, investigating the use of wood wastes in soil rehabilitation.

Fertilization Until the 1980s, forest-fertilization research in coastal British Columbia by CFS, Ministry of Forests, university, and industrial researchers concentrated on Douglas-fir and western hemlock, with later studies examining sites with unique problems (e.g., stagnating plantations on northern Vancouver Island soils with thick forest floors—Salal Cedar Hemlock Integrated Research Project [SCHIRP]). These trials have provided ecological and nutritional criteria for identifying responsive sites, empirical evidence for the magnitude of responses, and improved understanding of the fate and dynamics of applied nitrogen fertilizers.

In the interior, fertilization studies began in the early 1980s, and initially emphasized nitrogen fertilization of lodgepole pine. Results from these early studies indicated that other nutrient deficiencies were often induced following nitrogen additions, thereby limiting the responsiveness of fertilized stands. Subsequent research studies have evaluated the effects of other nutrients added in combination with nitrogen, and have confirmed that many sites in the central interior benefit from sulfur additions. The responsiveness of other species (e.g., hybrid interior spruce, "wet-belt" Douglas-fir, and aspen) is also being documented. Long-term fertilization installations have recently been established to document the extent to which intensive, repeated fertilization can increase productivity and thus mitigate reductions in annual allowable cuts that may result from a shrinking area allocated to timber production. Nine of these "maximum productivity" installations have been established in various Biogeoclimatic Ecosystem Classification (BEC) zones throughout the interior. Funding is required for the long-term assessment of this extensive network of growth-and-yield research installations.

Research gaps

Site preparation This area was discussed briefly in Section 2.1 Disturbance Management. The "five basic needs" for site preparation should help fill the knowledge gaps.

For tillage, a new program should be considered on soils where rooting depth is considered limiting and the nature of the unfavourable subsoils is conducive to amelioration through deep tillage that does not adversely affect topsoil structure.

Soil amendments This area was discussed briefly in Section 2.2 Soil Rehabilitation.

In urban and co-generation areas, there will be increasing need to dispose of residues and waste water. Therefore, in addition to the "five basic needs," work on co-generation residues should be considered.

Soil fertilization

a) Expanding the database of forest fertilization responses to enable better stand-level decisions:
   - Further research is needed to understand the nutrient requirements and fertilization response mechanisms of western hemlock, as well as

further empirical research on other coastal species (e.g., amabalis fir, western redcedar).

- Additional response information is needed for hybrid interior spruce, and for mid- and late-rotation lodgepole pine (possibly in combination with commercial thinning).
- Information on the response of mixed-species and high-elevation forests to fertilization is needed.
- Research is needed to document whether fertilization of young stands can promote faster "green-up" and thus affect the timing of adjacent harvesting.
- Further research is needed to document the effectiveness of fertilization in breaking repression in severely overstocked lodgepole pine stands.
- Collaboration with tree breeders offers important opportunities to document interactions between fertilization or foliar nutrient status and genotype.

b) Soil nutrient management and ecosystem processes:

- For "maximum-productivity" trials involving repeated fertilization, the array of nutrient-addition treatments has created important opportunities for understanding below- and above-ground processes across gradients of nutrient availability. Topics of particular importance include: dynamics of fine root biomass, soil biological responses, humus forms, litter decomposition rates, foliar nutrient balance, and tree form.
- What is the medium- and long-term fate of fertilizer elements, and how is this affected by fertilizer form?
- Does fertilization have any potential role in mitigating the susceptibility of stands to forest health problems? Can foliar nutrient imbalance created by large nitrogen additions negatively affect forest health?
- Are there unique nutrient management issues on soil types with distinctive chemical characteristics (e.g., calcareous soils)?
- For sites where the economic case for nitrogen fertilization is marginal, is the protection of natural nitrogen-fixation processes (e.g., symbiotic, associative) a more appropriate strategy for maintaining site fertility and productivity?

c) The role of forest fertilization in carbon sequestration:

- Are the long-term effects of fertilization on carbon sequestration in both biomass and soil organic matter significant in British Columbia forests? If so, does the potential value of carbon sequestration credits change the economics of forest fertilization?

Operational trials, adaptive management, and similar opportunities

Operational demonstration areas have been established to determine the influence of repeated nutrient additions on habitat structure and diversity, and on the abundance and diversity of small-mammal populations.

Links to policy, guidelines, plans, Timber Supply Reviews, and strategic direction

- The Forest Practices Code's direction on fertilization will be adjusted based on upcoming and new research results (e.g., Forest Fertilization Guidebook).

- The Timber Supply Review's productivity projection for managed forests will continue to be refined by research and operational trials. Improved understanding of the magnitude and controls of forest fertilization responses will assist timber supply planning by enabling more accurate prediction of yield gains from intensive management.
- Forest Renewal BC's key Strategic Objectives are supported by research in this area, for example:

  Sustainable Harvest— research in this area will contribute to guiding investments in soil fertilization and amendments based on longer-term research results and testing of the assumption that rehabilitated areas will contribute to timber supply.

  Enhancing Environmental Values—research in this area is directly applicable to efforts to restore damaged ecosystem.

  Strengthening Sustainable Forest Management—developing sustainable methods for enhancing productivity can take the pressure off other parts of the landbase to allow for enhanced management of other resource values.

Indicators of sustainability Research in this area addresses several indicators listed by the Canadian Council of Forest Ministers, including:

Criterion 2.0 Maintenance and enhancement of forest ecosystem condition and productivity,
Criterion 3.0 Conservation of soil and water resources, and
Criterion 4.0 Forest ecosystem contributions to global ecological cycles.

Comments on extension needs Nutrient deficiency diagnosis and fertilizer prescriptions represent a high demand for extension and consultation. The development of decision tools to reliably select responsive stands and to make appropriate fertilizer prescriptions will remove much of the uncertainty surrounding fertilizer operations.

2.4 Soil Landscape Variability

Soil is an integral part of the landscape and varies within the framework of landforms and parent materials. Forest planning and forest operations are based on certain knowledge of the soil and how soil properties vary over a given area. More work is needed to understand the variation of soil properties over these landscapes, and to determine the appropriate level of sampling for specific types of planning or research.

With the increasing trend toward landscape-level planning and modelling, landscape-level soil information is becoming more important. Old soil surveys are now becoming more available under various Geographic Information Systems and Information Banks. Development and implementation of new soil inventory techniques may be appropriate for some types of spatially specific planning and modelling.

Issue Quantify soil (site productivity) variability at the landscape and stand levels to help guide management and investment decisions, and maximize the utility of landscape-level soil information.

Existing research Historically, soil maps and soil mapping formed the foundation of investigations and interpretations related to land capability for forestry, soil suitability for engineering uses, and even slope stability and

erosion interpretations. Considerable investigation occurred during the large Canada Land Inventory and B.C. Land Inventory programs of the late 1960s and the 1970s. Soil variability was a topic of research interest during the late 1970s and early 1980s. Since that time, scientists originally involved in these investigations moved into remote sensing and terrain stability fields or policy environments.

In the United States, considerable work continues on soil inventory and mapping at more detailed scales to allow operational use, providing input to management and investment decisions. In British Columbia, Terrestrial Ecosystem Mapping (TEM), Predictive Ecosystem Mapping (PEM), Terrain Stability Mapping, erosion interpretations related to Watershed Assessment, and some types of watershed hydrologic modelling all have some base in the principles of soil mapping.

Research gaps

Soil mapping (including interpreting baseline site productivity) Large areas of the operating forest have reconnaissance-level soil mapping, which may be considered under-utilized in some landscape planning and Timber Supply Reviews. It is critical to establish baseline productivity levels as a context for the tree-growth implications (positive or negative) of soil-disturbance management, soil restoration, and investigating the potential for enhancing soil productivity. Areas that warrant investigation include:

- Development of soil-based productivity estimates, including areas of previous disturbance. Use of these estimates in management and investment decisions.
- Use of general mapping for landscape-level interpretations (e.g. trafficability for planning seasonal operations).
- Viability of more detailed soil mapping in conjunction with PEM/TEM or Terrain Stability Mapping.
- Use of soil maps as input to predicting windthrow hazard.
- Use of soil inventories to ensure representation of below-ground ecosystems, based on distinct soil types or unique properties.
- Development of a GIS database to interact with other computer models that are used to plan harvesting, road-building, inventories, Timber Supply Reviews, etc.

Biogeoclimatic site series and soils Response of plant communities to soil moisture and nutrient regimes is the cornerstone of the biogeoclimatic system used in British Columbia. There is an excellent opportunity to further develop understanding of ecosystems by examining plant and soil interactions within the site-series framework. This information will help researchers in the future as they examine how forest management affects plant and soil interactions. Baseline data, such as foliar nutrient concentrations, have not been well documented by site series. Other topics include organic matter dynamics, litter chemistry, and humus form development and classification.

Satellite research Some work has been done on PEM/TEM and windthrow hazard.

Operational trials, adaptive management, and other opportunities Most of these topic areas are very conducive to operational trials.

Links to policy, guidelines, plans, Timber Supply Reviews, and strategic direction There is opportunity for policy and plans to be more closely linked to soil inventories and GIS soil maps and interpretations.

Indicators of sustainability Research in this area addresses several indicators listed by the Canadian Council of Forest Ministers, including:

Criterion 2.0 Maintenance and enhancement of forest ecosystem condition and productivity, and
Criterion 3.0 Conservation of soil and water resources.

Comments on extension needs As soil maps become more available under various Geographic Information Systems and information banks, there is a need to tell potential users what soil maps are and what they are not, and to provide extension on interpretations under development such as those related to windthrow and soil trafficability.

At the operational level, the same principles apply to site stratification for silviculture prescriptions, and these need to be portrayed to those mappers and users of such information.

Provide soil science support to the vision that British Columbia will be universally recognized as a leader in sustainable management of forests and grasslands.

Prevention of detrimental soil disturbance is preferred to remediation because it is less expensive and more likely to protect the soil. Existing Forest Practices Code regulations concerning soil conservation are based on research and best available information. The goal of soil-conservation research is to better understand the principles and practices of sustainable soil management and to translate this improved understanding into better management practices.

3.1 Long-term Soil Productivity

Various forest practices can lead to depletion of organic matter that is on the soil surface or that is available for decomposition over the course of a forest rotation. Machine-based operations can also create soil compaction that, in the lack of data to the contrary, is considered to last at least for many decades. Understanding the implications and acceptable limits of these processes may be considered the foundation of sustainable soil management.

Issue Participate in the international long-term soil productivity network by maintaining and developing benchmark study sites to determine long-term effects of soil disturbance (organic matter loss and soil compaction) to test and demonstrate sustainable forest management, and to support guideline revisions.

Existing research

Older research installations A few older research installations included compaction as a study component. These include some CFS and Ministry of Forests sites related to skid roads and stump-removal trials. Some forest industry, FERIC, and university trials also include compaction. All these should be considered for periodic re-measurement if not already planned.

Larger, integrated studies mentioned in Section 3.2. Soil Ecology often also include a component of soil physical properties, and also an organic matter component.

Long-Term Soil Productivity (LTSP) study This is a recent initiative over the last 10 years that follows an international protocol developed with the USFS. The broad objectives of the study are to investigate and demonstrate how soil compaction and organic matter retention (site disturbance) affect forest productivity over the long term, and to gain an understanding of how the fundamental processes controlling productivity are affected by this site disturbance. Twelve installations are in place or in progress in British Columbia (similar installations occur in many of the forested regions of the United States, and elsewhere in the world).

The British Columbia installations are: three sites in the Peace River region (BWBS); one each near Smithers, Prince George, and Williams Lake (SBS); three sites near Kamloops (two complete, one in progress)(IDF); and three sites near Invermere (one complete, two in progress)(calcareous soil IDF). A new installation has been proposed for the Interior Cedar-Hemlock

zone near Nelson, to pair with a single replicate in Idaho. All sites have been in place for 7 years or less.

Satellite LTSP research trials

- The CFS is establishing related, "miniplot" studies at the Invermere installations. Soil-rehabilitation plots are also being installed in Invermere.
- Studies of decomposition have been installed at the SBS sites, and a UBC decomposition study will be installed at the Kamloops sites.

Research gaps in LTSP and most other studies

- Long-term results.
- Rehabilitation installations at all sites.
- Incorporation of smaller dispersed disturbance ("miniplots") where possible.
- Other climates: the coast, ESSF, and ICH.
- Silvicultural systems other than clearcutting (e.g., effect of repeated entries on compaction and organic matter).
- Include a range of low- and high-productivity sites.
- Data collected at these sites will be suitable for carbon cycling and global climate change modelling.

Links to other policies, plans, and documents

- FRBC Strategic Objective 3, investment in usable, timely information and tools keyed to achieving sustainable forest management.
- FRBC Strategic Objective 2, especially with respect to rehabilitation of old logging roads.
- Support and refinement of soil conservation sections of the Forest Practices Code.

Indicators of sustainability Research in this area addresses several indicators listed by the Canadian Council of Forest Ministers, including:

Criterion 2.0 Maintenance and enhancement of forest ecosystem condition and productivity, and
Criterion 3.0 Conservation of soil and water resources.

Comments on extension needs Results from the LTSP study have already been used to determine operational windows in northeastern British Columbia aspen stands. Soil conservation issues and the research on which the regulations are based are on-going topics of interest and concern to the forest industry and forest district staff.

3.2 Soil Ecology (Below-ground Biodiversity

Issue Develop better understanding, active management strategies, and appropriate indicators of soil biodiversity and below-ground ecosystem function, processes, and components, including natural disturbance regimes.

Existing research

Soil and harvesting disturbance impacts and amelioration A few multi-disciplinary, long-term research projects with some focus on soil ecology have been established in the province. These include SCHIRP, Montane Alternative Silvicultural Systems (MASS), Sicamous Creek Research Project, Date Creek Silviculture Systems Research Project, and the LTSP study. For instance, soil physical, chemical, and biological parameters are being assessed relative to soil compaction and organic matter loss as part of the LTSP study. Responses of soil faunal, mycorrhizal, and macrofungal communities to timber harvesting have been studied at some of these sites.

Research is on-going into the role of indigenous, introduced, and augmented root-inhabiting and rhizosphere organisms (mycorrhizal fungi, plant growth-promoting rhizobacteria, potential root-rot biocontrol agents, etc.) in measures of ecosystem function after various harvesting disturbances. Examples include: 1) inoculation of stumps with native *Hypholoma fasciculare* to control *Armillaria ostoyae*, and 2) inoculation of conifer seedlings with commercially available mycorrhizal fungi to assess performance on roads, on landings with and without rehabilitation, and on cutblocks.

Preliminary assessment of biological communities in soil under lodgepole pine has shown that there are measurable differences in the communities of mycorrhizal fungi and soil mesofauna and in soil microbial activity after repeated fertilization.

Soil ecosystem function It has been demonstrated that different plant species, including trees and shrubs, can share the same mycorrhizal fungi and that nutrient transfers between plants can occur via these fungi.

Various studies are beginning to show that communities of soil organisms and macrofungi differ based on various site and stand attributes. These communities change with timber harvesting and the result may be predictable patterns of community composition and response. This is particularly important for the management of biodiversity in general, and of commercially important fungi (such as pine mushroom and Armillaria root rot) in particular.

Decomposition of litter has received a relatively large amount of research attention, but the role of coarse woody debris and of organic amendments (e.g., disposal of wood wastes) has received relatively little.

Very few studies have specifically addressed provincial issues of soil biota biodiversity, including issues of soil and canopy arthropods, macrofungi, and bacteria.

Non-timber forest products Some research has been carried out on habitat preference of pine mushroom. In the Prince Rupert Forest Region, for instance, this research has been applied to the mapping of potential pine mushroom habitat based on ecological site series.

Research gaps Long-term trials will help answer the important question, "what are the responses in soil organisms over time, as forest stands develop after establishment, and what are the relationships between these changes and forest productivity?"

- There is a need to understand the functional significance of below-ground changes resulting from timber harvesting, site disturbance, and soil amelioration.
- Root rots become more of concern on some sites after harvesting. Continued work is needed, in conjunction with pathologists, to understand soil conditions related to these trends.
- The goal of rehabilitating disturbed soils should not be simply to grow trees; the goal should include re-establishing functional soil communities and systems. Scientists and resource managers need to know how to do this and how to determine if it is has been successful.
- The LTSP study also offers the opportunity for assessing various levels of site disturbance (organic matter loss and soil compaction) on carbon budgets.
- Support is needed for determining tree biomass volumes, vegetation (non-tree) biomass estimates, soil carbon pools (including coarse woody debris), soil carbon pool decay rates, and carbon dioxide emissions in response to site disturbance and in relation to site productivity.
- The dynamics of soil nutrients in response to ecosystem disturbance and the factors that control soil nutrient availability are still not well understood.

Soil ecosystem function

- There is still a tremendous amount to learn about soil ecosystems, soil organisms, soil processes, soil development, and the effects of forest management on soils.
- There are huge gaps in the basic knowledge about soil-dwelling species and communities.
- There is a need to understand the functional significance of below-ground interactions, such as mycorrhizal linkages, to tree growth and to other ecological integrators.
- Understanding how the interconnected processes of litter and wood decomposition, mineralization, and nutrient losses may be influenced by levels of canopy or structural (snag) retention during harvest is key to understanding long-term sustainability of forest management.
- There is a need to build improved understanding of soil processes, pools, and dynamics into forest ecosystem management models.
- Testing should be undertaken to determine whether the *Soil Conservation Guidebook* or *Biodiversity Guidebook* are adequately addressing and protecting the functioning of soil ecosystems.

Natural disturbance processes (e.g., fire, slope instability, sedimentation, pathogen outbreaks) are recognized as key drivers of forest ecosytem dynamics. This theme has become a major focus of forest ecology research during the past decade, both at the stand and landscape levels. However, this work has emphasized above-ground processes almost exclusively, with little attention given to below-ground effects. New research needs to address questions such as:

- In steep, mountainous landscapes, what roles do natural disturbance processes play in both sequestering and mobilizing soil organic matter and nutrients?

- How do soil properties reflect the imprint of natural disturbances?
- How do the effects of natural disturbances compare to those of management practices, both in their magnitude and frequency? What might this comparison reveal about the resilience and recovery of the below-ground components of ecosystems?

Non-timber forest products (NTFPs)

- Habitat preferences of most commercially harvested forest mushrooms have yet to be been studied in the province.
- Site conditions that favour productivity of commercially important forest mushrooms and ways of enhancing productivity need to be determined.
- Economic assessment of the value of NTFPs is needed, as are policy recommendations relative to managing and evaluating the whole forest resource, relative to NTFPs.

Operational trials, adaptive management, and similar opportunities

Non-timber forest products

- Trials to assess effects of various harvesting systems on commercially important forest mushrooms are needed. These should be integrated with assessment of all forest resource values including timber and botanical NTFPs such as boughs, berries, etc.
- Innovative means of mapping potential NTFPs and assessing their economic worth for specific management areas are needed. Venues for this type of work include Community Forest Pilot Projects, Enhanced Forest Management Pilot Projects, First Nations territories, and forest districts.

Links to policy, guidelines, plans, Timber Supply Reviews, and strategic direction

Effects of harvesting disturbance, soil amelioration, and soil system function

- Research into soil ecology addresses issues in the Forest Practices Code as covered under the *Soil Conservation Guidebook*, the *Biodiversity Guidebook*, and the *Root Disease Management Guidebook*.
- It supports FRBC Strategic Objectives 1 (Sustainable Harvest) and 3 (Strengthen Sustainable Forest Management [Enhance Knowledge]).
- Research findings in soil ecology can affect Timber Supply Reviews, and Land and Resource Management Plans.

Non-timber forest products

- Research and development of NTFPs supports FRBC Strategic Objectives 4 (Strengthen and Expand the Value-Added Sector), 5 (Support Forest Workers through Transition), and 6 (Support Forest Communities Experiencing Major Job Loss).
- Research findings on NTFPs will affect the Timber Supply Reviews, and Land and Resource Management Plans. Eventually, the development of Non-Timber Forest Product Supply Reviews may occur.

Indicators of sustainability Research in this area addresses several indicators listed by the Canadian Council of Forest Ministers, including:

Criterion 1.0 Conservation of biological diversity.
Criterion 2.0 Maintenance and enhancement of forest ecosystem condition and productivity.
Criterion 3.0 Conservation of soil and water resources.
Criterion 4.0 Forest ecosystem contributions to global ecological cycles.
Criterion 5.0 Multiple benefits of forests to society.

Comments on extension needs Effects of forest management on soil organisms and processes are topics of interest for many individuals and groups. For example, the effects of timber harvesting on a purportedly rare and endangered mushroom on the Sunshine Coast was the focus of a complaint to the Forest Practices Board a few years ago. NTFP management and development presents an area of growing demand for consultation and information.

3.3 Soil–Vegetation Interactions

Issue Understand interactions between plants and soils to improve our ability to predict and document the effects of forest management decisions and support guideline revisions.

Existing research Litter decomposition is one of the more studied soil and plant interactions, in British Columbia and elsewhere. Some studies have documented the effects of species (e.g., deciduous vs. coniferous), litter quality effects (nitrogen and lignin), and microclimate effects.

Coarse woody debris has also been studied. Recent work elsewhere has indicated that rotting wood acts as an important moisture reservoir and as a center of mycorrhizal and free-living nitrogen fixation activity. In British Columbia, some research on the role of coarse woody debris has begun in experiments such as the LTSP study.

Mycorrhizal fungi and nutrient transfer among plants has been studied elsewhere and to a limited extent in British Columbia (e.g., Douglas-fir and birch; the interactions between conifer and broadleaf species and soil properties and nutrient cycling). It has been demonstrated that different plant species including trees and shrubs can share the same mycorrhizal fungi and that nutrient transfers between plants can occur via these fungi. Some shrub species can harbour mycorrhizal fungi that are important to planted conifers.

Soil-borne plant diseases and pests can dramatically affect the growth of crop trees and other species. The causal agents of many diseases and infestations are now known and research into the means of controlling outbreaks is being carried out. There is some research into the role that pests and disease play in forest succession.

Research gaps

Mechanisms and controls of soil ecosystem functions Positive and negative feedbacks between plants and soils control essential processes such as nutrient cycling and affect ecosystem function. For example, trees can respond to relatively infertile soils by producing needle litter with higher concentrations of condensed tannins. Tannins may reduce potential leaching losses of nitrogen from the ecosystem. Other examples include species such as cedar and broadleaves that accumulate bases in their foliage, thereby

encouraging decomposition. Understanding these types of interactions between plants and soils will greatly improve our ability to document the effects of forest management.

We need to develop a more holistic model of decomposition and its effects on ecosystems and the implications of forest management. This would contribute to the research priorities of forest productivity, sustainability, and carbon cycling.

The effects of disease and pests on ecosystem function and their responses to forest management are two areas where more research is needed. For instance, analysis of soil conditions conferring soil suppressiveness and of the ecological implications of any biocontrol techniques is important.

Role of seral vegetation Seral vegetation might play an important role in mediating and ameliorating soil properties. In managed forests, including partially cut forests, intermediate vegetative stages are often short-circuited to speed the return of forest cover consisting of desired crop trees. Changing the natural successional patterns of seral vegetation may alter soil characteristics in ways that have implications for the sustainable management of forests. Ecosystems often have a component of deciduous trees that might also play an important role in maintaining soils. The effects of natural disturbance regimes on soil development and fertility is fundamental to managing the soil resource, including productivity expectations. Long-term research of vegetation management effects is needed and probably possible through assessment of previous site preparation trials.

Coarse woody debris The removal of wood is one way in which managed forests are distinctly different from natural forests. Losses in forest productivity and stability in Europe, for example, could in part be explained by the long-term removal of wood from the ecosystem. More detailed studies are required to fully examine the implications of woody debris on soil processes.

Links to policy, guidelines, plans, Timber Supply Reviews, and strategic direction

- This research has relevance to various silvicultural practices such as vegetation management and to the *Tree Wounding and Decay Guidebook* and the *Root Disease Management Guidebook.*
- This research is also linked to Forest Renewal BC Strategic Objective 3: Strengthen Sustainable Forest Management (Enhance Knowledge).

Indicators of sustainability Research in this area addresses several indicators listed by the Canadian Council of Forest Ministers, including:

Criterion 1.0 Conservation of biological diversity.
Criterion 2.0 Maintenance and enhancement of forest ecosystem condition and productivity.
Criterion 3.0 Conservation of soil and water resources.
Criterion 4.0 Forest ecosystem contributions to global ecological cycles.
Criterion 5.0 Multiple benefits of forests to society.

Comments on extension needs Retention of coarse woody debris and management of competing vegetation are important issues in forest management in British Columbia. Effects and control of pests and disease are driving timber harvesting in parts of the province.

A summary of the detailed discussion presented herein on forest and range soils research is contained in the Executive Summary, starting on page v.

Environment Canada (1999)[2] provided a detailed analysis of the current state of knowledge and future needs in addressing the requirements of the Kyoto Protocol and probable future agreements on land use, land-use change, and forestry. With respect to forest and range soils, the relevant areas are listed in Appendix 1 of this plan, and summarized below:

- There is a need for national inventories of carbon stocks in forest ecosystems, in agricultural soils, and in wetlands, as well as the understanding of the interactions between diverse systems, which are inadequate to provide a baseline against which to measure change.
- There remain some important uncertainties as to how physical and chemical processes within land ecosystems, and particularly soils, take up carbon dioxide from the atmosphere, transfer it as carbon compounds within the ecosystems, and retain it within the system as a carbon reservoir or release it again into the atmosphere. These processes vary significantly from one location to another and with time. They are also sensitive to anticipated changes in environmental conditions such as temperature and precipitation, atmospheric concentrations of carbon dioxide, and acidic deposition.
- There is a poor understanding of how the carbon stock in the total carbon system changes, particularly in below-ground, dead organic and dissolved organic carbon pools within ground and surface water.
- Improvements are needed in techniques for confidently scaling up data on changes in carbon stock in highly variable ecosystems from the process level to ecosystem, landscape, and national scales.

Priorities for action

- **Baseline information** There is an urgent need to maintain, enhance, and develop databases of soils, wetlands, climate, land cover, and management practices.
- **Monitoring systems for detecting change** Well-designed and long-term benchmark monitoring and assessment systems can overcome ecosystem carbon variability. For some areas of research, particularly wetlands, coordination mechanisms need to be established to provide leadership and focus.
- **Scaling systems** Better use needs to be made of existing databases to link carbon flux processes to larger-scale variables such as forest stand type and age classification, wetland classification, soil hydrology regimes, land-use practice, etc.
- **Soil composition and decomposition** Improved understanding of soil composition, and of decomposition processes, including aerobic vs. anaerobic and autotrophic vs. heterotrophic processes, in Canada's forests, agricultural sector, and wetlands.
- **Response to soil disturbance** Improved understanding of response of carbon fluxes and storage to management practices, to global and regional environmental change, including climate change and carbon dioxide and

2 Environment Canada. 1999. Sinks Table Options Paper: Land-Use, Land-Use Change and Forestry in Canada and the Kyoto Protocol, 23 Sept. 1999. Ottawa, Ont

nitrogen inputs, and to disturbances such as fire, insects, floods, and droughts.

- **Modelling soil carbon** Development of reliable carbon dynamic models at the ecosystems and landscape levels.

The report recommended a number of studies including:

- Data on litterfall and other large plant residue inputs to dead organic matter pools on permanent sample plots should be collected and compiled. Data on decay rates in various ecosystem types across Canada should be developed and compiled. The link should be maintained between litter/dead organic matter parameter databases and the national carbon accounting system.
- Special attention should be given to the effects of stand history on the size of dead organic matter pools, which will differ greatly between stands that were previously affected by logging and those affected by wildfire or insects. Methods and inventory information need to be developed that assist in the determination of stand history and the resulting amounts of dead organic matter pools in forest ecosystems across Canada.
- Incorporation of a detailed coarse woody debris and soil carbon monitoring systems into the National Forest Information System that is currently under development.
- Improved methods for parameterization and quantification of carbon dioxide efflux from soils and roots by stand type, stand age, and nutrient regime at daily, seasonal, and annual scales, across climatic regions, as affected by weather and climate.
- Improved measurements of the decay of wood residues on site, 0–10 years after harvest.